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Performance of Mechanical Properties of Hybrid Aluminium Based Metal Matrix Composites

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***Abstract* - A metal matrix composite is a composite material with at least two constituent parts, one being a metal and the other may be a different metal or some other material, such as a ceramic or organic compound. When three or more materials are present, it is called a hybrid composite. Aluminium is used as a matrix element owing to its lesser weight and found to be the best alternative with its unique capacity of designing a material to give desired properties. In this paper, production of hybrid aluminium based metal matrix composites by using liquid metallurgy stir- casting method and to investigate the various mechanical properties like tensile strength, yield strength, percentage elongation, impact strength and hardness have been identified by varying weight fraction of Silicon carbide and Titanium dioxide ceramic powder in the following proportions i.e. Aluminium LM6 90%, Silicon Carbide 5%, Titanium dioxide 5% , Aluminium LM6 84%, Silicon Carbide 9%, Titanium dioxide 7% and Aluminium LM6 86%, Silicon Carbide 11%, Titanium dioxide 3%.The Mechanical behavior of these composites are found individually and the internal structures were observed by using Scanning Electron Microscope(SEM).**

Keywords— aluminium LM6; silicon carbide; titanium dioxide; stir casting; SEM

I. INTRODUCTION

Aluminium metal matrix composites have been of interest as engineering materials because of their higher specific strength and stiffness. Since they have distinct advantages in aerospace, automotive and other structural applications their fatigue behavior is an important factor that must be considered. The interest in aluminum alloys discontinuously reinforced with ceramic particulates has grown considerably. Normally the reinforcement materials generally used to reinforce aluminum alloys include carbides (SiC and Tic), Borides (TiB_2 and ZrB_2) and oxides (Al_2O_3 and SiO_2). Here the Aluminum silicate particulate is chosen due to its attraction over high elastic modulus and it can partially replace the titanium oxide in their application with its low cost. Some of the literature surveys have been studied in regarding with the particulate metal matrix composites.

A. Matrix

The matrix is the monolithic material into which the reinforcement is embedded, and is completely continuous. This means that there is a path through the matrix to any point in the material, unlike two materials sandwiched together. In structural applications, the matrix is usually a lighter metal such as aluminum, magnesium, or titanium, and provides a compliant support for the reinforcement. In high-temperature applications, cobalt and cobalt–nickel alloy matrices are common.

Fig. 1. Stir Casting Machine

II. Literature Review

Asit Behera et al [1] studied the Tribological behaviour of $Al_2O_3/TiO_2/Cu$ composite by using pin-on-disc wear Machine, For all structural/functional application, tribological properties of material play most prominent role in day to day life. Tribology arises when there is a relative motion between two surfaces that are in contact resulting loss of mass from surface by rubbing. To restrict this type of wear suitable lubricant can be used. This paper describes about wear behavior of three composites specimen made from constituting elements: alumina oxide, titanium dioxide and copper with the help of pin on disc machine. These three specimen pellets are made by powder metallurgy technique by increasing the furnace temperature from 1000ºC to 7000ºC with a rate of 30ºC/min. From wear test, wear rate graphs are plotted with respect to sliding velocity. In this study it is found that, composition of composites and sliding velocity majorly impart on wear rate. Our present aim is to test the mixture of various compositions of alumina and titanium in a copper base and test it for its different properties, to compare it with pure alumina. Among three composite it is observed that more the amount of TiO_2 percentage, lesser is the wear rate. This investigation can help to improve the tribological properties of surfaces by varying their composition.

Fig. 2. Preheating Machine

H. Shin et al [2] studied the Effect of the TiO_2 nanoparticle size on the decomposition behaviors in aluminum matrix composites. The decomposition behaviors and the effect of particle size on the kinetic rate are studied for Al–3 Vol% titanium dioxide (TiO_2) composites by using three different types of TiO_2 particles (15, 50, and 300 nm). Thermal analysis shows that the reaction is stepwise with the first reaction starting before the melting temperature of Al. Since the high chemical potential of nanoparticles enhances reactivity, the TiO, Al_3Ti, and α-Al_2O_3 phases are found to be formed during the first reaction regardless of particle size. Based on observations of microstructure, the formation mechanism of Al3Ti and α-Al_2O_3 is understood to be solution precipitation. Non-isothermal kinetic analysis reveals that the reaction mechanism is closely related to the three-dimensional continuous nucleation and the growth limited by diffusion. Particle size is found to be having considerable effect on the kinetic rate. As the particle size decreases, the rate constant increases, while the pre-exponential factor and the activation energy decreases. A non-linear relationship between the rate constant and the reciprocal of the size is found and evaluated.

J.H. Shin et al [3] studied the Evolution of the interfacial layer and its effect on mechanical properties in TiO_2 nano particle reinforced aluminum matrix composites, For aluminum based composites reinforced with titanium dioxide (TiO_2), the variations of the interface layer during annealing and their effect on mechanical properties have been investigated. Three different types of reinforcing TiO_2 particles (i.e., 15, 50, and 300 nm) are used, and the composites are annealed at 500 °C for up to 24 h. The small 15 nm particle with high chemical potential energy can induce the enhanced decomposition process, leading to the extension of the interfacial layer during up to 12 h of annealing, in which Ti and O atoms are alloyed in an aluminum structure. The alloyed interface layer has beneficial effects on mechanical properties of aluminum based composites in terms of the elastic modulus and yield stress. Furthermore, elongation to failure increases since the alloyed interfacial layer does not interfere with the movement of dislocations emitted at the interface of the particle, which continuously decomposes and shrinks during annealing. Further annealing stimulates the reduction processes, inducing the formation of α-Al_2O_3 and Al_3Ti in the layer. When the particle size is 300 nm, the interfacial evolution behavior cannot be observed at the interface due to the negligible decomposition behavior of the particle under the annealing condition.

Y.A.Sorkhe et al [4] studied the Mechanical alloying and sintering of nanostructured TiO_2 reinforced copper composite and its characterization Mechanical alloying is a suitable method for producing copper based composites. Cu–TiO_2 composite was fabricated using high energy ball milling and conventional consolidation. Ball milling was performed at different milling durations (0–24 h) to investigate the effects of the milling time on the formation and properties of produced nanostructured Cu–TiO_2 composites. The amount of the TiO_2 in the final composition of the composite assumed to be 0, 1, 3, 5 and 7 wt%. The milled composite powders were characterized by X-ray diffraction, scanning electron microscopy and transmission electron microscopy to investigate the effects of the milling time on the formation of the composite and its properties. Also hardness, density and electrical conductivity of the sintered specimen were measured. High energy ball milling causes a high density of defects in the powders. Thus the Cu crystallite size decreases, generally to less than 50 nm. The maximum hardness value (105 HV) of the sintered compacts belongs to Cu–5 wt%TiO_2 which has been milled for 12 h.

G. Kumaresan,et al [5] studied the Experimentation of a Rectangular Cup Formation of Al 7075 Alloy in Superplastic Forming Process , Superplastic behaviour of certain metals and alloys having very fine grains, very large tensile elongations are obtained within certain temperature ranges at low strain rates. In this work, Al-alloy superplastic sheet material was considered. The AA 7075 sheets were subjected to the modified thermomechanical treatment, to obtain the average grain size of 10 µm in less processing time. These alloys can be formed into complex shapes by superplastic forming, a process that employs common metalworking techniques. This paper aims to study the formability, thickness distribution, cavitation effect and microstructure feature for aluminium material by considering variable parameters such as forming pressure from 0.2 MPa, 0.3 MPa and 0.4 MPa and the sheet thickness of 2 and 1.5 mm. The 2 mm sheet gives better results of 0.4 MPa for both high thinning factor of 0.9466 and less cavity volume fraction of 4.4%.

III. Problem Description

The main objective of this project is to prepare the hybrid aluminium metal matrix composite material aluminium LM6 reinforced with silicon carbide and titanium dioxide materials in various proportions and to analyze and compare the various mechanical properties with aluminium LM6.

A. *Scope*

The scope of work is limited to applications where aluminium is used. Instead of other metals like steel we prefer aluminium because of corrosion resistant and less weight. So our proposed aluminium alloys can be used in many fields where aluminium is used.

IV. Working Methodology

The titanium dioxide & silicon carbide Ceramics are taken in correct proportions by weight measuring machine to that of aluminium (LM6) and melted combined in preheating machine and mixed with Titanium dioxide and silicon carbide in stir casting machine for a minute and then taken in a bowl and poured in to dies.

V. Experimental Procedure

In this work the investigation focuses on SiC and TiO_2 particulates reinforcement on Aluminium LM6.

A. *Tensile Test*

The tensile test is the best-known test in material testing. It determines tensile strength, one of the most important properties of material. Further more, it is also possible to determine elongation at fracture as a toughness measurement of the material.In the tensile test, a mono-axial stress is generated in a material sample. This stress is induced via external loading of the sample in a longitudinal direction via a tensile force.There is then an eve distribution of direct stress in the test cross-section of the sample. In order to determine the strength of the material, loading of the sample is slowly and continuously increased until its fails.The maximum test force occurring is a measurement of the strength of the material.

Tensile strength and Yield strength of specimen 1 was found to be more as it contain the combination of Aluminium LM6 (86%), Titanium dioxide (3%), Silicon Carbide (11%). Tensile strength and Yield strength of specimen 2 is greater then specimen 3 but less then specimen 1 because the percentage of silicon carbide is less in specimen 3.

TABLE I. Tensile Properties of Composites

Materials	**Aluminium LM6 86%, Titanium dioxide 3%, Silicon Carbide 11%**	**Aluminium LM6 84%, Titanium dioxide 7%, Silicon Carbide 9%**	**Aluminium LM6 90%, Titanium dioxide 5%, Silicon Carbide 5%**
Tensile Strength in MPa	181.53	132.6	121.66
Yield Strength in Mpa	168.86	119.39	109.52
% Elongation	6.4	22.8	18.8

Elongation of specimen 2 was found to be more as it contain the combination of Aluminium LM6 (84%), Titanium dioxide (7%), Silicon Carbide (9%). Elongation of specimen 3 is greater then specimen 1 but less then specimen 2 because the percentage of Titanium dioxide is more in specimen 2.

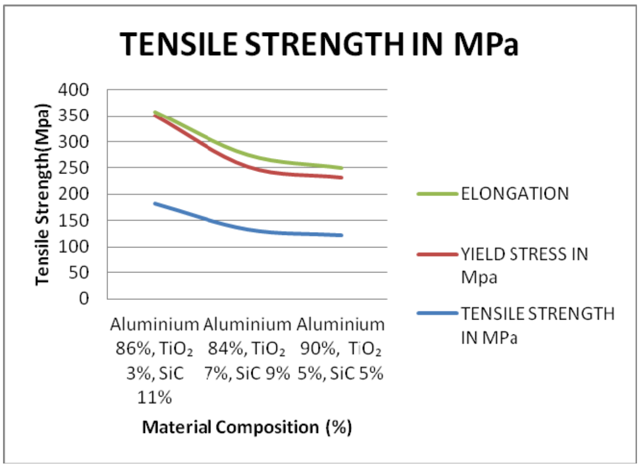

Fig.3. Tensile Strength Values

B. *Flexural Load Test*

Flexural strength, also known as modulus of rupture, bend strength, or fracture strength, a mechanical parameter for brittle material, is defined as a material's ability to resist deformation under load. The transverse bending test is most frequently employed, in which a specimen having either a circular or rectangular cross-section is bent until fracture or yielding using a three point flexural test technique. The flexural strength represents the highest stress experienced within the material at its moment of rupture. It is measured in terms of stress, here given the symbol σ.

TABLE II. Flexural Properties of Composites

Materials	Al LM6 (86%)+TiO_2 (3%)+ SiC (11%)	Al LM6 (84%) +TiO_2 (7%)+ SiC (9%)	Al LM6 (90%) +TiO_2 (5%)+ SiC (5%)
Flexural Load in kN	5.44	3.77	5.73

Flexural load of specimen 3 was found to be more as it contain the combination of Aluminium (90%), Titanium dioxide (5%), Silicon Carbide (5%). Flexural load of specimen 1 is greater then specimen 2 but less then specimen 3 because the percentage of Aluminium is more in specimen 3.

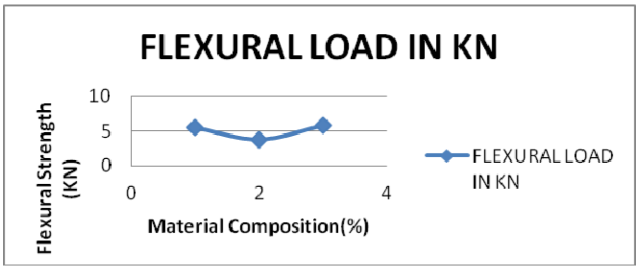

Fig. 4. Flexural Load Values

C. Compression Test

When a specimen of material is loaded in such a way that it extends it is said to be in tension. On the other hand if the material compresses and shortens it is said to be in compression.On an atomic level, the molecules or atoms are forced apart when in tension whereas in compression they are forced together. Since atoms in solids always try to find an equilibrium position, and distance between other atoms, forces arise throughout the entire material which oppose both tension or compression. The phenomena prevailing on an atomic level are therefore similar.The strain is the relative change in length under applied stress; positive strain characterises an object under tension load which tends to lengthen it, and a compressive stress that shortens an object gives negative strain. Tension tends to pull small sideways deflections back into alignment, while compression tends to amplify such deflection into buckling.Compressive strength is measured on materials, components and structures. The apparatus used for this experiment is the same as that used in a tensile test. However, rather than applying a uniaxial tensile load, a uniaxial compressive load is applied. As can be imagined, the specimen (usually cylindrical) is shortened as well as spread laterally.

TABLE III. Compression Properties of Composites

Materials	Al+TiO_2 (3%) + SiC(11%)	Al+TiO_2 (7%)+ SiC(9%)	Al+TiO_2 (5%)+ SiC(5%)
Compression Load in kN	48.31	30.17	48.26

Compression Load of specimen 1 was found to be more as it contain the combination of Aluminium LM6 (86%), Titanium dioxide (3%), Silicon Carbide (11%). Compression Load of specimen 3 is greater then specimen 2 but less then specimen 1.

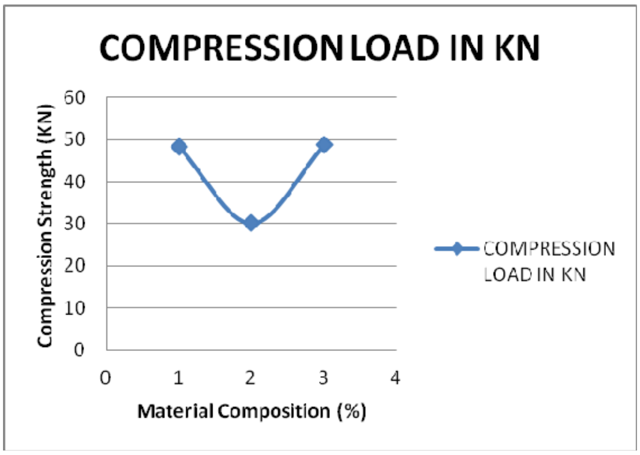

Fig. 5. Compression Load Values

D. Hardness Test

Hardness is one of the most basic mechanical properties of engineering materials.Hardness test is practical and provide a quick assessment and the result can be used as a good indicator for material selections. This is for example, the selection of materials suitable for metalforming dies or cutting tools. Hardness test is also employed for quality assurance in parts which require high wear resistance such as gears.

TABLE IV. Hardness Properties of Composites

Materials	Al+TiO_2(3%) + SiC(11%)	Al+TiO_2(7%) + SiC(9%)	Al+TiO_2(5%) + SiC(5%)
Hardness in BHN (10/500 kgf)	60.9	34.4	37.7
	61.7	34.2	37.9
	61.3	33.9	37.5

Hardness of specimen 1 was found to be more as it contain the combination of Aluminium LM6 (84%), Titanium dioxide (3%), Silicon Carbide (11%). Hardness of specimen 2 is greater then specimen 1 but less then specimen 3 because the percentage of Silicon carbide is more and Titanium di oxide is less in specimen 1because of silicon carbide is more.

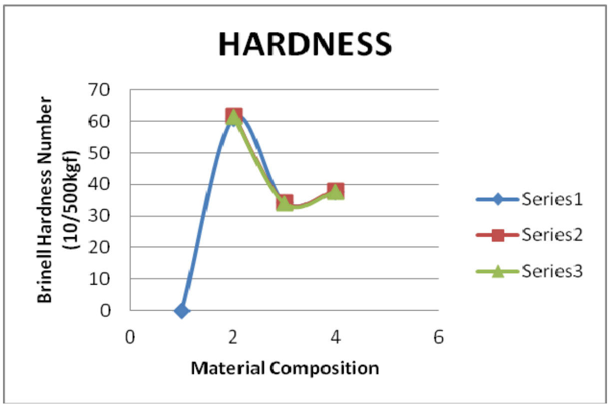

Fig. 6. Hardness Values

E. *Izod Impact Test*

In the Izod impact test, the test piece is a cantilever, clamped upright in an anvil, with a V-notch at the level of the top of the clamp. The test piece is hit by a striker carried on a pendulum which is allowed to fall freely from a fixed height, to give a blow of 120 ft lb energy. After fracturing the test piece, the height to which the pendulum rises is recorded by a slave friction pointer mounted on the dial, from which the absorbed energy amount is read.

TABLE V. Impact Properties of Composites

Materials	Al+TiO_2 (3%)+ SiC(11%)	Al+TiO_2 (7%)+ SiC(9%)	Al+TiO_2 (5%)+ SiC(5%)
Impact Strength in Joules	4	16	22

Impact values of specimen 3 was found to be more as it contain the combination of Aluminium LM6 (90%), Titanium dioxide (5%), Silicon Carbide (5%). Impact values of specimen 2 is greater then specimen 3 but less then specimen 1 because the percentage of silicon carbide is more.

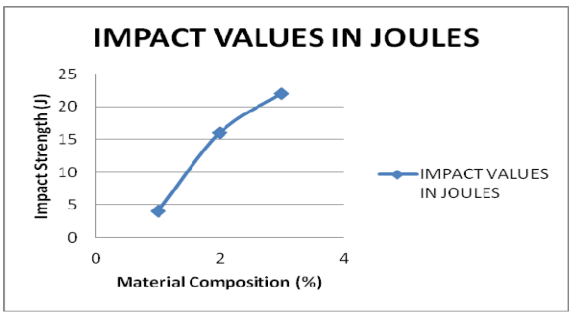

Fig. 7. Impact Values

VI. Result and Discussion

Hybird metal matrix composites containing various percentages of Aluminium(LM6),TiO_2 and SiC were studied. Three such samples were taken and various mechanical properties tests were conducted and analysed by scanning Electron Microscope. The specimen which shows good results in both mechanical test and SEM analysis.

VII. Microstructure Analysis

Particle distribution was evaluated with the help of scanning electron microscope. The casting procedure was examined under the SEM to determine the reinforcement pattern and cast structure. A section was cut from the castings. They were grinded using 100 grit silicon carbide paper followed by 220, 400, 600 and 1000 grades of emery paper and polished and etched by Keller's reagent to obtain a better contrast.The specimens were visualized on different magnifications (100x, 250x,500x,750x and 1.00kx) to show the presence of reinforcements and its distribution on the metal matrix different elements/ compounds which were present in the titanium dioxide and silicon carbide are difficult to distinguish by SEM.

The following are the SEM analysis images for the following specimens.

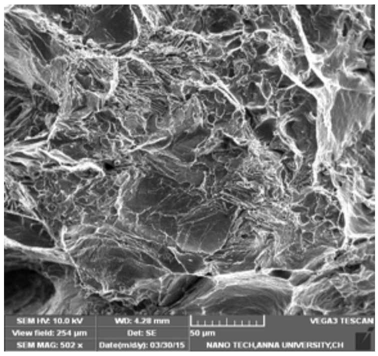

Fig. 8. Aluminium LM6 86%, Titanium Dioxide 3%, Silicon Carbide 11% at 500x

The above image shows the morphological structure of the sample containing aluminium (LM6)86%, titanium dioxide3% and silicon carbide11%. Silicon carbide and titanium dioxide are completely dispersed in the aluminium matrix leading to high tensile strength and yield strength.

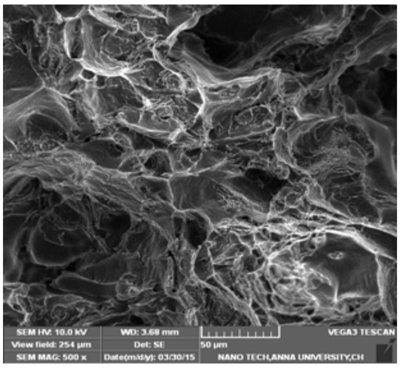

Fig. 9. Aluminium LM6 84%, Titanium Dioxide 7%, Silicon Carbide 9% at 500x

The above image shows the morphological structure of the sample containing aluminium(LM6)84%, titanium dioxide7% and silicon carbide9%. and it reveals that partical distibution in the matrix was uniform. it may chance to cause corrosion through porosity increasing the precentage of titanium dioxide

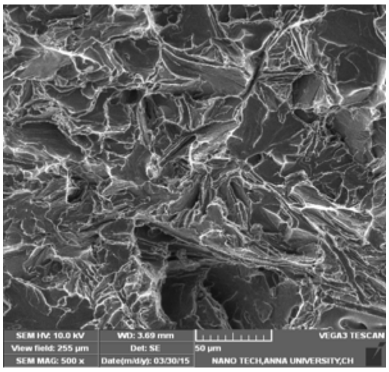

Fig. 10. Aluminium LM6 90%, Titanium Dioxide 5%, Silicon Carbide 5% at 500x

The above microstructure reveals that the particle distribution in the matrix was uniform. it was clear that the corroision of matrix occur due to the equal weigth fraction of titanium dioxide5% and silicon carbide5%. and it results reduction in strength and hardness.

VIII. CONCLUSIONS

The following of conclusion derived from the hybrid aluminium LM6 composites.

- Aluminium LM6 reinforced with Titanium dioxide and Silicon carbide were obtained as a desire raw material.
- Aluminium LM6 matrix containing 3:11,7:9 and 5:5 weight fraction of Titanium dioxide and silicon carbide as reinforcement were fabricated by stir casting method.
- The various mechanical properties test was conducted successfully.The Tensile strength, yield strength, compression strength and hardness was significantly increased for Aluminium LM6 86%, Titanium dioxide 3%, Silicon Carbide 11%.
- The impact strength and percentage elongation was increased and other properties are significantly reduced for the Aluminium LM6 90%, Titanium dioxide 5%, Silicon Carbide 5%.
- From the microstructure, it has been observed that has homogenous distribution and excellent binding of Titanium dioxide 3% and silicon carbide 11% particulates with aluminium LM6 86% matrix and significantly less binding with uniform distribution of Aluminium LM6 90%, Titanium dioxide 5%, Silicon Carbide 5%.

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